VIRTUAL HEATING PLANTS

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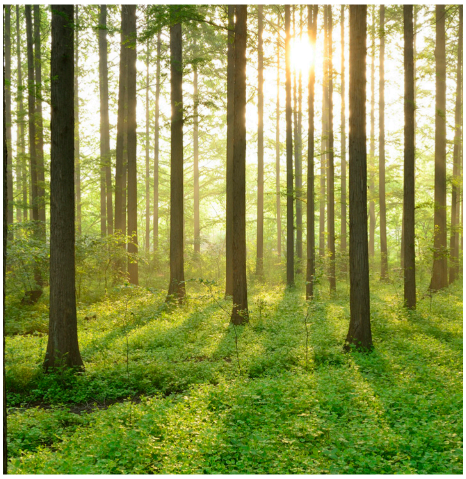

Virtual Heating Plants

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Foreword

An advantage with district heating systems is their ability to utilize residual heat from various sources. As more digital technologies are implemented in society, the need for data centers has increased and thus the residual heat from the centers. The project *Virtual Heating Plant* aims to identify opportunities and challenges with liquid cooling of data centers and investigate how high temperatures can be extracted from liquid-cooled servers.

The project was led and conducted by Mattias Vesterlund together with Erik Lundmark at RISE Research Institute of Sweden. A reference group consisting of Niklas Lindmark, Gävle Energi (chair); Henrik Landersjö, E.ON; Staffan Stymne, Norrenergi; Stefan Hansson, Kraftringen och Svante Carlsson, Skellefteå Kraft has followed the project and assured the quality and the usability of the results.

The project is part of the FutureHeat program, with the long-term goal to contribute to the vision of a sustainable heating system with successful companies that utilize new technological opportunities and where the investments made in district heating and cooling are utilized to the best of their ability.

This project is part of the second phase of the program. The FutureHeat program is led by a steering committee consisting of Jonas Cognell, Göteborg Energi (chair); Anders Moritz, Tekniska verken i Linköping; Anna Hinderson, Vattenfall AB; Charlotte Tengborg, E.ON Värme Sverige; Fabian Levihn, Stockholm Exergi; Holger Feurstein, Kraftringen; Patrik Grönbeck, Borlänge Energi; Leif Bodinson, Söderenergi; Lena Olsson Ingvarson, Mölndal Energi; Magnus Ohlsson, Öresundskraft; Niklas Lindmark, Gävle Energi; Per Örvind, Eskilstuna Strängnäs Energi & Miljö; Petra Nilsson, Växjö Energi; Staffan Stymne, Norrenergi; Stefan Hjärtstam, Borås Energi och Miljö; Svante Carlsson, Skellefteå Kraft; Ulf Lindquist, Jämtkraft and Julia Kuylenstierna (coopt), Energiforsk.

Deputies have consisted of Ann Britt Larssson, Tekniska verken i Linköping and Peter Rosenkvist, Gävle Energi.

Julia Kuylenstierna

Summary

Data centers can replace existing heating plants in a district heating system if the right cooling technology is used and IT hardware can achieve the same power intensity. A testbed has been created to support the technological development of liquid-cooled data centers. The goal is to be able to create excess heat that does not need heat pumps to be used in a district heating network.

The project aims to demonstrate the opportunities and obstacles that exist to switch from air cooling to liquid cooling of data centers, with it being able to allow data centers to constitute as virtual heating plant in the district heating system. The specific cost of liquid cooling is normally more expensive compared to traditional air cooling, by selling the excess heat as district heating there are opportunities to repay that additional cost within a few years.

A data collection from existing data centers and heat production plants shows that the specific power intensity of a data center can in some cases correspond to a heating plant a district heating system. With today's development towards more powerful servers and the use of GPUs for HPC calculations, the power intensity will increase and make data centers more competitive and attractive as heat sources. An evaluation of different possibilities for connections of the data center to the district heating network shows that the data center can be connected as a traditional heat production facility. Where water from the return line is extracted and heated to be returned to the supply line, to achieve the desired temperature, the flow through the plant is adjusted.

At ICE data center research facility (RISE), a testbed has been established that enables the evaluation and development of liquid cooling techniques and products. The testbed is connected to the property's domestic hot water and hot water circulation system in the same way as a possible heat production plant. The highest temperature reached on the excess heat is 72 ° C in a lab test, it is suitable for a 4th generation or a low-temperature district heating system. To upgrade to high-temperature district heating, only a small heat pump stage is needed, compared to lifting from 35 ° C, which is normal for an air-cooled data center.

To enhance the use of liquid cooling in data centers for heat recovery the biggest obstacles are; the additional cost for more expensive technology, knowledge of the properties of the technology, lack of cooperation models, and division of ownership responsibility between the data center owner and the recipient of the surplus heat.

Keywords

Data center, District heating, Liquid cooling, Excess heating, test bed.

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Designations

Abbrevations

CFD	Computational Fluid Dynamics
DC	Data Center
DH	District Heating
DH-P-R	Return flow for primary side in a district heating
DH-P-S	Supply flow for primary side in a district heating
DH-S-R	Return flow for secondary side in a district heating
DH-S-S	Supply flow for secondary side in a district heating
HMI	Human Machine Interface
LCT	Liquid Cooling Testbed
PDU	Power Distribution Unit
TORs	Top of Rack Switches
UPS	Uninterruptible Power Supply
VV	Hot water pipe
VVC	Hot water circulation line
T&D	Test and Demo

Word explanation

Input	input / data
Output	output / result

1 INTRODUCTION

1.1 BACKGROUND

Today we use more and more digital tools and services to facilitate our everyday life and work. To enable the function of these tools, data and computing power is required where data centers and other infrastructure are used to handle calls and requests.[1] The computing power consumes electricity both for operation and for cooling, the heat that is created is difficult to use due to its low temperature range and that air is usually used as a transport medium. However, there are alternative coolants and methods that use liquids instead of air in different configurations, for example on-chip, where a heat exchanger is mounted directly on the processor or immersion cooling, where the servers are immersed in a bath of, for example, mineral oil.[2] These methods do not need to first transfer the heat from the electronics to air and then from air to any other means of transport such as water and can thereby achieve higher temperatures.[3]

There are several actors on the market that today offer liquid cooling solutions, but they often find it difficult to compete with traditional air-cooled alternatives and are therefore usually opted out. A general trend is that data center owners are increasingly demanding the possibility of being able to recover heat from their plant, and there is also a lobbying activity that discusses and pushes for legislation that regulates the use of surplus heat from industry.

To drive development forward, RISE (Research Institutes of Sweden AB) has established a research facility for data centers in Luleå (ICE Datacenter), where broad research is conducted in the data center area. One track in the research is to test and evaluate different applications for the excess heat, mainly air-based applications have been studied. There is a need for a corresponding liquid-cooled test bed, which can demonstrate and demonstrate the possibilities that exist with liquid-cooling instead of air.

1.2 DATA CENTER

Data centers and surrounding areas use many abbreviations and English terms to describe daily operations. This section focuses on explaining how a data center works and operates and describes the refrigeration techniques used.

1.2.1 General

A typical data center (DC) uses electricity to power IT equipment (ICT) in the form of servers, switches (for data networks) and data storage, which often corresponds to about 45% of the total energy consumption. The remaining 55% of the energy is used for the operation of the data center (Facility Usage) to cool off the heat created

[1] Geng, 2014
[2] Day, Lin & Bunger, paper 265
[3] Lin & Day, paper 279

when the servers work, losses in the power supply and for peripherals such as fans and lighting and more.[1]

The energy distribution between ICT and Facility Usage varies depending on the data center's geographical location, where the outdoor climate has a major impact on the electricity demand for cooling. The increased attention to data centers energy use has also led to improvements being made that reduce cooling and electricity needs in recent years.

The main purpose of a data center is to assist with functions such as websites, cloud storage, streaming services. The requirements for these services to be available to end users are normally very high, which is why there are often high requirements for the availability of the electricity supply.

To ensure that operation does not stop, UPSs (Uninterruptible Power Supply) are used[1] as well as backup generators. UPSs also help filter out interference and harmonics generated by the servers against and from the grid that may affect the servers.[4] Reserve generators are used to be able to ensure electricity supply to the data center in the event of longer power outages from the electricity supplier, normally the reserve power consists of diesel generators.

The power requirement for a server varies depending on the model, make and year of manufacture. For many years, developments in IT equipment have followed Moore's law[5] which says that the number of transistors in a processor will double every 18 - 24 months, which means that development has constantly progressed and that the servers can be replaced with newer ones that are more energy efficient.

A standard server at ICE Datacenter in Luleå consumes approx. 400 W at maximum load. A modern processor can (processor only) consume up to 400 W as well as a modern GPU[2] (Graphics card). Since it is common for a server to be equipped with dual processors, the power can be estimated at 800 W per server for a modern server.

Some servers can be equipped with GPUs, if the server is equipped with 2 GPUs, the potential use increases to 1200 W. It could be considered as HPC (High Performance Computing) which is used as a generalization for servers with high computing power. Compared to a typical server, HPC for example supports parallel calculations and a computing capacity of over 10^{12} teraflop.[6]

1.2.2 Common components

A data center consists of a number of servers that perform the IT work, and they are often placed in special cabinets called racks or server racks. At the top of the server rack are often one or more network switches (Top of Rack, TORs) that ensure that the servers can communicate with each other and with the outside world.

[4] Rasmussen, 2010
[5] Colwell, 2013
[6] High Performance Computing

To contribute power to both servers and switches, Power Distribution Units (PDUs) are used to distribute power to the servers. Typically, dual PDUs and dual PSUs (Power Supply Units) are used on the servers to provide redundancy where the different PDUs are fed from different electrical systems (Dual Feed to Dual Rack PDUs) and hence in the event of a power failure of one electrical system, data center operation is not affected.[1] There are many types of configurations but the one presented above is the most common.

Server racks are often placed in rows opposite each other, creating aisles that are often divided into cold and hot aisles. A hot aisle is the space behind the servers and the rack where air is used to cool the servers and the hot air ends up in the hall. The function of the aisles is to provide space for technicians to be able to perform service, maintenance, and other work with the equipment. The advantage of separating hot and cold running from each other is that more efficient cooling is achieved by avoiding hot and cold air mixing with each other. To improve air separation, walls, or other boundaries (hot- and cold aisle containment) are often installed that force the cold air to pass only through the servers.

1.3 COOLING OF DATA CENTERS

Cooling is a fundamental prerequisite for data center operations that aims to transport the heat away from the data center to the surrounding outdoor environment.[7]

There are mainly two different techniques used today: air cooling and liquid cooling or a combination of the two techniques.

During the transition from air to liquid, the server fans are replaced with a liquid pump. What the specific effect difference, i.e., how much electricity is used to drive the fan or pump per server is not clear today. This is currently being investigated at ICE Datacenter.

There is a rule of thumb that says that when the rack power is higher than 20 kW, liquid cooling must be applied. At such powers, it is difficult to create sufficient airflow needed to cool an air-cooled rack.

1.3.1 Air cooling

Air-cooled data centers are the most common and most applied technology today. For this technology, air is mainly used to transport and cool away the heat that is created when the servers are working. Heat sinks and smaller fans are normally mounted on the servers.

There are several different techniques that can be used to transport the heat from the server room for cooling to the outdoor air (Figure 1).[7]

CRAH

Computer Air Handling Units (CRAH) is the unit consisting of one or more fans and a heat exchanger which in turn is connected to a cooling machine. The hot air

[7] Evans, paper 59

is sucked in by the fans and the air is forced through the heat exchanger where it is cooled to a desired temperature and then released into the server room again. An advantage of set-up is that the cooling machine can be placed outside the data center environment where there is more space and also facilitates service when technicians never need access to the data center environment to service the cooling machine.

In order for the cooling machine to get rid of the heat, there are three different techniques that can be used,

1. Cooling tower, where water evaporates with the condenser heat of the cooling machine, i.e., phase transition to water vapor takes place towards the outdoor air.
2. Dry cooler with brine circuit, where glycol-mixed water connected to a fan and heat exchanger placed outdoors.
3. Condenser, where a refrigerant and a compressor circuit together with a condenser placed outdoors.

Sometimes extra compressor stages with separate heat exchangers are also placed inside the cooling machine together with a glycol circuit and a dry cooler to enable free cooling when the outdoor temperature allows, but compressor cooling is available in warmer climates, i.e., a combination of techniques 2 and 3 above.

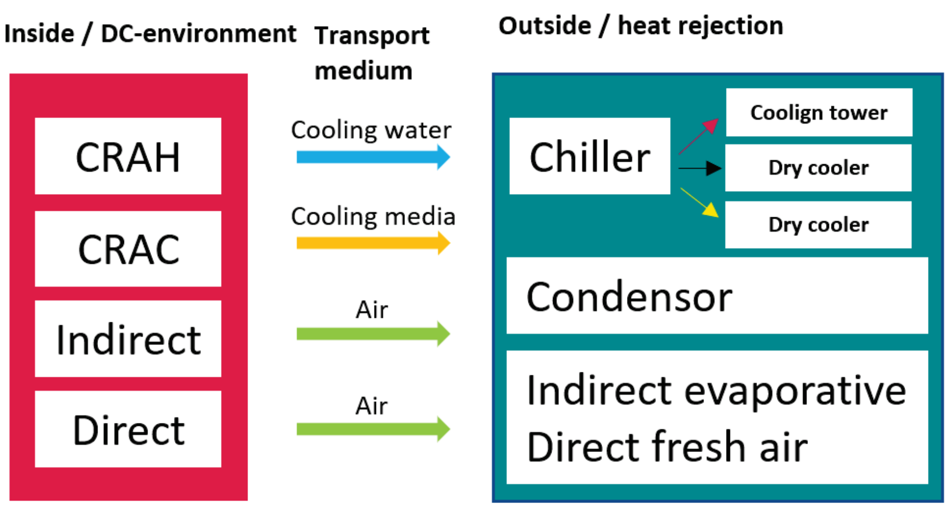


Figure 1: Four common air cooling techniques with a focus on illustrating similarities and differences between the techniques.

CRAC

Another common alternative to CRAH units is a Computer Room Air Conditioner (CRAC) where the difference is that a cooling machine has been placed in each CRAH unit. Which means that the means of transport from the CRAC unit, which is placed in the data center environment, is a refrigerant that is cooled in a condenser placed outdoors.

The CRAC unit also has fans just like the CRAH unit for cooling the air in the data center, but an evaporator instead of a heat exchanger for the transition from air to water and a compressor (cooling machine).

Indirect evaporative cooling

A third and common cooling technique is indirect evaporative air cooling where outdoor air cools the data center via an air-to-air heat exchanger to ensure that the data center air is kept clean and isolated from the outside world. This cooling technology is usually supplemented with a DX unit as a backup and the outdoor air is sometimes sprayed with water to cool the air and improve the cooling capacity.

Direct evaporative cooling

There is also direct evaporative air-cooling technology where the outdoor air is directly blown in and cools when the outdoor climate allows, which is the technology that Facebook used in Luleå for its data centers. If it gets too cold, some of the hot exhaust air can be mixed with the cold incoming air to achieve the desired temperatures and during the hot summer months, the air can also be sprayed with water to cool better and to carry away more heat. The result is a very cheap cooling system where only fans are needed to cool, and the data centers are placed. In the northern climates, free cooling can then be used all year round.

1.3.2 Liquid cooling

As the processors decrease in size, their specific power also increases, which places greater demands on more efficient cooling, especially when the use of GPUs has increased where a server can be equipped with several GPUs and each GPU can emit a heating power up to 400 W.[2]

Listed below are some pros and cons of liquid-cooled data centers:

+ More energy-efficient cooling, takes up less space when servers can be packed more tightly as a result of liquids having a better heat transfer capacity in relation to air. By using liquid instead of air as a heat carrier, more than 4000 times more energy can be extracted for the same unit of volume and degree.

+ Less noise, when the server fans can be replaced with central pumps that have a lower noise level.

+ By replacing fans with pumps for liquid cooling, more efficient data centers can be obtained, which means that less electrical power goes to the cooling equipment.[8] This can provide an energy saving of 4 - 15% per server.

+ Reduced heat loss, especially if the system is insulated.

[8] Lei & Masanet, 2020

+ Easier heat recovery when supply temperatures to the liquid cooling can start from 30 °C, which opens for new areas of use such as district heating which has been impossible with traditional air cooling.[3]
- More difficult to install and maintain, when more work is needed to first dry the servers or disconnect the liquid cooling system before servicing the servers can begin.

Liquid cooling can be divided into two main categories: On-chip cooling (Direct to Chip) and Immersion cooling, where the servers are immersed in a dielectric liquid (Figure 2).

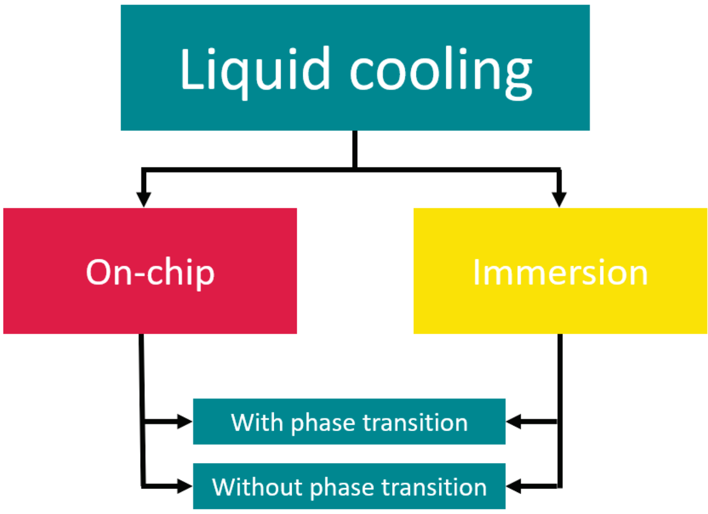


Figure 2: The two main categories for liquid cooling of servers.

On-Chip cooling

For On-chip cooling (or direct chip cooling), liquid is led directly to the hottest components such as processors or GPUs where dedicated cooling blocks are used to dissipate heat. Sometimes the technology is supplemented with cooling blocks for frame memories and other less energy-intensive components, and it is estimated that 50 - 80% of the heat can be recovered.[7]

The technology can also be used with the help of a liquid where phase transition from liquid to gas can take place and hence the latent heat required at the transition can be used for more efficient heat removal.[7]

Immersion cooling

An alternative variant of liquid cooling of servers is instead to use a bath where the entire server is immersed in a dielectric liquid, this variant can also use latent heat and phase transition. Via this method, over 95% of the generated heat can be picked up and removed by the liquid.[7] By using immersion cooling, a higher energy density in the data center can be obtained, which means that new applications can be applied.[9]

In summary, with liquid cooling, higher temperatures of excess heat and energy density can be achieved as well as more efficient data centers.

1.3.3 Simulation tools

To be able to make assessments and evaluations for different cooling techniques and surplus heat applications at data centers, a variety of tools can be used. The most common is to use some form of simulation tool. When it comes to studies of air and water flows, it is common for a CFD analysis to be carried out that provides an opportunity to study velocity and temperature profiles. The results can also be used for dimensioning a plant based on the results.

CFD stands for "Computational Fluid Dynamics", which is a tool that via computer power creates flow simulations and flow predictions of fluids using the conservation laws (energy, momentum and momentum conservation, and the conservation of electrical charges).

Furthermore, the calculations are based on defined geometries and specified boundary conditions.[10] It enables realistic simulations on non-existent and drawn geometries where, among other things, heat conduction and liquid flows can be calculated based on physical models.

1.4 DISTRICT HEATING

District heating systems are usually classified into four main categories; first, second, third and fourth generation district heating [23].[11] The first generation used steam as a heat carrier and was built until the 1930s.

For the second generation district heating, pressurized water was used instead to withstand temperatures above 100 °C and was the primary technology until the 1970s, where the pipes were generally placed in concrete culverts with pipe heat exchangers for heat transfer. This technology is still found today in many Swedish systems.

The third generation district heating is the most common technology today and has been used since the 1980s even though it was introduced as early as 1970. It is reminiscent of the second generation district heating with the difference that lower temperatures in the network are used and other material choices are used where the components are more material efficient, prefabricated and insulated with polyurethane foam and plastic case that are welded together on site.

The fourth generation of district heating has the main focus on lowering the supply and return line temperatures in the network to, for example, 50 ° C / 20 ° C.[11] The finesse of lowering the temperature range is increased opportunities to integrate renewable energy sources such as solar and geothermal energy, but also the

[9] Nadjahi, Louahlia & Lemasson, 2018
[10] Howard, 2012
[11] Lauenburg, 2018

utilization of waste heat from industries, which has been difficult in previous generations.

In order to make district heating more competitive and to be able to provide a heat source for more buildings, the industry faces a challenge to be able to include cheap surplus heat in its systems. One possibility for this is to use excess heat from data centers and to achieve the desired temperature, heat pumps need to be used.[12, 13, 14, 15, 16]

Today, there are several data center facilities connected to district heating systems, for example Stockholm (Stockholm data parks), Falkenberg (GleSYS), Vallentuna (E.ON) where all use heat pump solutions to upgrade the excess heat to district heating temperatures. Heat pump systems at approximately half the data center power normally need to be installed to be able to recover the excess heat to the district heating network, which can be a problem in cities where there is already a shortage of power. This also means that significant investments need to be made, which makes it more difficult to put together the business calculation.

1.5 TECHNOECONOMICS

Techno-economic analysis is a tool for demonstrating technical and economic possibilities, advantages and technical limitations for a given system. It is usually based on a process model that generates basic mass and energy balances and serves as a starting point for process optimization, cost calculation and evaluation of environmental impact.

This project uses techno-economic calculations to evaluate the additional cost of using liquid cooling and the opportunity provided by the sale of the surplus heat as district heating in a low-temperature system.

1.6 PURPOSE AND GOAL

The purpose of the project is to demonstrate the opportunities and obstacles that exist to switch from air cooling to liquid cooling of data centers, which will be done by answering the following questions and objectives:

[F.1] What is the highest possible liquid temperature extracted and how could it be implemented in today´s and future district heating systems?

[F.2] How can the power intensity of a datacenter be increased by using liquid cooling instead of traditional fan cooling?

[F.3] How is the power intensity affected by the computing density of the server cluster?

[F.4] Quantify the additional cost of using liquid cooling?

[12] Wahlroos, Pärssinen Manner & Syri, 2019
[13] Koronen, Åhman & Nilsson, 2020
[14] Antal, Cioara, Anghel, Gorzenski, Januszewski, Oleksiak, Piatek, Pop, Salomie & Szeliga, 2019
[15] Zhang, Wang, Wu, Shi & Li, 2015
[16] Davies, Maidment & Tozer, 2016

[F.5] What connection principles are there in the market and how appropriate are they in data center contexts?

[F.6] Evaluate and rank proposals for technical liquid cooling and heat recovery solutions for implementation in district heating systems.

[F.7] Identify and evaluate any remaining obstacles to the implementation of the liquid cooling technology.

[F.8] Establishment of test bed that provides the opportunity for demonstration of the recovery of excess heat from a liquid-cooled data center.

1.7 VIRTUAL HEATING PLANT

To answer and work with the questions above, an application was made for the Virtual Heating Plant project at Energiforsk with co-financing from InterReg Nord via the Arctig-DC project.

1.7.1 InterReg Nord

Arctiq-DC[17] is an EU-funded project via InterReg Nord and another nine project partners from both Finland and Sweden with RISE as coordinator for the project. The purpose of the project is to strengthen the regional data center industry's services, products, solutions and offerings to customers outside the region, nationally or internationally. To succeed in this, there is an objective to prove by demonstrating and using measurements that there are very good conditions for operating and investing in data centers in the subarctic regions. This is because these regions have among the lowest operating and investment costs in the world when it comes to power distribution and cooling.

1.7.2 Energiforsk

Energiforsk[18] is a research company with a focus on disseminating knowledge and coordinating research with energy as its focus. The company also hopes to be able to have an impartial and central part and contribute with benefits for the energy system of the future. It is a non-profit business owned by Svenska Kraftnät, Energiföretagen Sverige, Energigas Sverige and Nordion Energi. Energiforsk contributes with many research programs where one of these programs is called Futureheat[19] with a collection of projects focusing on conducting research and development in thermal ecosystems.

A requirement for all projects within Futureheat was to have a reference group where Virtual Heating Plant's reference group consisted of members from the following energy companies in Sweden E.ON, Gävle Energi, Norrenergi, Kraftringen and Skellefteå Kraft.

[17] InterReg Nord
[18] Energiforsk
[19] Futureheat

2 Method

The main focus of the section is to provide an overall methodological description of how the work has been conducted to answer the questions that the project aims to answer.

2.1 TEMPERATURE SIMULATION

To achieve the highest possible temperature from the servers, heat simulations were performed in CFDs to find the method with the greatest potential.

The simulations were performed in the Ansys CFX software where geometries were drawn together with a model for a server with heat sinks. It is then meshed and finally simulated with given parameters, for example CPU power, temperature before the CPU and the flow. All simulations were tested with some variations of input data such as temperature and flow for the inlet. After the simulations, the results were analyzed to find which concept and which input result resulted in the highest temperatures. To improve the model for the heat sinks, heat pipes were implemented, which is the small curved pipe that is found on some heat sinks. The heat pipe uses phase conversion to provide a more even temperature profile over the heat sink and in this way a better heat transport is created from the server to the air [17].[20]

2.2 TECHNOECONOMICS

What distinguishes the project's liquid-cooled system from others is that the focus is on extracting a value-added product in the form of district heating. In this way, the possibilities are demonstrated that liquid cooling solutions can be more competitive against a traditional air-cooled system. The annual heat energy (kWh) that can be extracted from a server plant can be calculated according to the following equation:

$$Heat\ energy = Power\ * 8760\ * utilization\ rate \qquad (1)$$

Where the power (kW) refers to the excess heat from the servers that is available for heat recovery, heat transfer losses are deducted. The utilization rate is defined as a factor between 0 - 1 which is multiplied by the time (which is 8760 hours in a year) and is a measure of how much of the time it is possible to load the servers heavily enough to produce district heating.

Then, to calculate an annual income (SEK), the district heating price (SEK / kWh) was used, which is site-specific and on an annual basis. Furthermore, the assumption is also made to be able to sell the district heating at a sales quota, where 1 means that a full district heating price is obtained for the heat and 0 that no compensation is received:

[20] Gren, Johansson, Kranenbrag & Ottosson, 2020

$$Annual\ revenue = Heat\ energy\ \frac{District\ heating\ price_{location,annual\ average}}{Sales\ ratio} \quad (2)$$

To make a financial calculation, a "direct repayment period" is used where only the income from district heating sales is included according to the equation below, which is the estimated price that the district heating company is assumed to be willing to pay for the surplus heat. Direct repayment period is defined here as the time it takes to recover the investment cost without considering ancillary costs such as maintenance costs or how inflation affects. The usual source of income, data power in the form of calculations and storage, is not included as it can be assumed to be the same regardless of which cooling solution is used. Any investment costs for connection to the district heating network, for example additional distribution lines, are also not included.

$$Repayment\ period\ = \frac{Installation\ cost}{Annual\ revenue} \quad (3)$$

Today, there are several district heating players who have developed a concept that buys and takes care of surplus heat from data center, e.g., Stockholm Exergi (Open District Heating[21]), Vattenfall (SamEnergi), Tekniska Verket i Linköping (Delad Energi).

The value and thus the ability to pay for waste heat varies between different district heating companies, e.g., depending on current alternative production, temperature levels and power guarantees. This project's recycling solution is assumed to be able to constantly deliver excellent district heating temperatures throughout the year. Therefore, a rough assumption is made here that the value of the surplus heat, as an average over the year, is half of the district heating company's current customer price for variable and fixed charges for district heating. This is assumed to correspond to a value in the upper range of the ability to pay for the excess heat, given the high temperature level and ability to contribute with a constant effect throughout the year.

For comparison, three scenarios are evaluated; Luleå, Tierp and an average for Sweden. What distinguishes them is the district heating price where all district heating prices are taken from EnergiFöretagen.[22]

Based on the server effect, the amount of useful heat energy in the economic statement was calculated. The heat energy was calculated for a whole year and based on that; an annual income could be calculated according to equation (2). With the result from the estimated annual income, a “direct repayment period” could be produced according to equation (3).

For most data centers, it is unreasonable to assume that their servers are always 100% loaded, as a measure of how large the load is, the term utilization rate is used. The degree of utilization is a measure of how much of the total installed IT

[21] Öppen fjärrvärme
[22] Energiföretagen

power is used and which with it could be available as district heating according to equation (1).

2.3 CONNECTION PRINCIPLES

Connecting a heat source to a district heating network is in principle relatively simple, on the primary side of the district heating network it is necessary (to the right side of the heat exchanger in Figure 3):

- Heat exchanger,
- Distribution pump,
- Temperature sensor,
- Pressure sensor,
- Control system.

The system either regulates the power of the heating system to maintain a desired temperature on the district heating network or alternatively the flow from the district heating network is regulated to maintain the desired temperature.

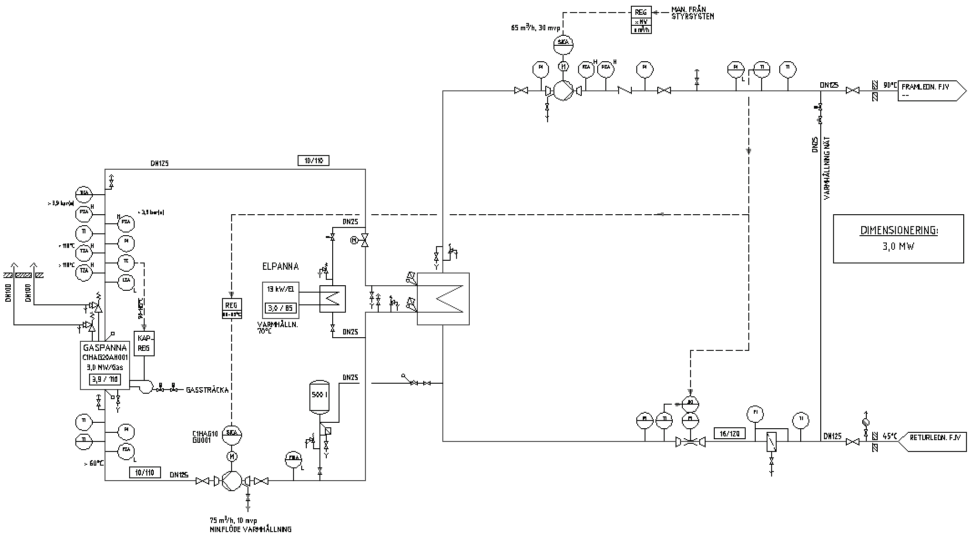


Figure 3: Examples of connection of heat source to a district heating system, to the right of the heat exchanger primarily district heating network and to the left heat source which can be a data center. (Gaspanna = gas boiler, gassträcka = gas distance, elpanna = electric boiler, minflöde varmhållning = minimum flow heating, framledning = supply line, dimensionering = dimensioning, returledning = return line)

Under normal operating conditions on a district heating network, the return temperature is between 40 ° C in winter and up to 55 ° C in summer, which is the initial temperature that a heating system needs to be able to receive and that the residual heat supplier must be able to use for its cooling needs.

2.4 LIQUID COOLING TEST BED

To demonstrate the possibilities that exist in creating district heating through immersion cooling of servers, a liquid cooling test bed (LCT) is set up at the ICE data center facility.

Since the district heating plant in the building in question is difficult to access, the goal is to produce domestic hot water instead of district heating. The test bed was set up within the ICE facility to be able to control all flows and temperatures. Since the district heating plant in the building in question is difficult to access, the goal is to produce domestic hot water instead of district heating. This is done by heating the hot water circulation (return line) to the hot water line (supply line). For those established by LCT, the following steps were needed:

- Connection principle
- Dimensions
- Installation
- User interface

The facility will be used to demonstrate live temperatures and how much energy has been recovered in the form of domestic hot water on an annual basis. Furthermore, other companies may also be able to carry out tests and development projects in the test bed in the future.

3 Results

This chapter reports the results from the work within the project virtual heating plants and the student projects that were carried out in the autumn of 2019 and 2020, as part of the education for civil engineering in sustainable energy technology and the degree project "construction and design of test beds for liquid cooling of data centers".

3.1 TEMPERATURE SIMULATIONS

Several flow and temperature simulations have been made to study different designs of the cooling fins for liquid cooling and the design of the concept for evaluation of flow control. Figure 4 shows the concept "tunnel" that was manufactured for evaluation.

The physical tests for the "tunnel" showed that it could raise the temperature from 40 ° C (the blue arrow) to 71 ° C (the red arrow) at a mass flow of 0.002 kg / s, which was achieved when the CPU temperature was 80 ° C.[20]

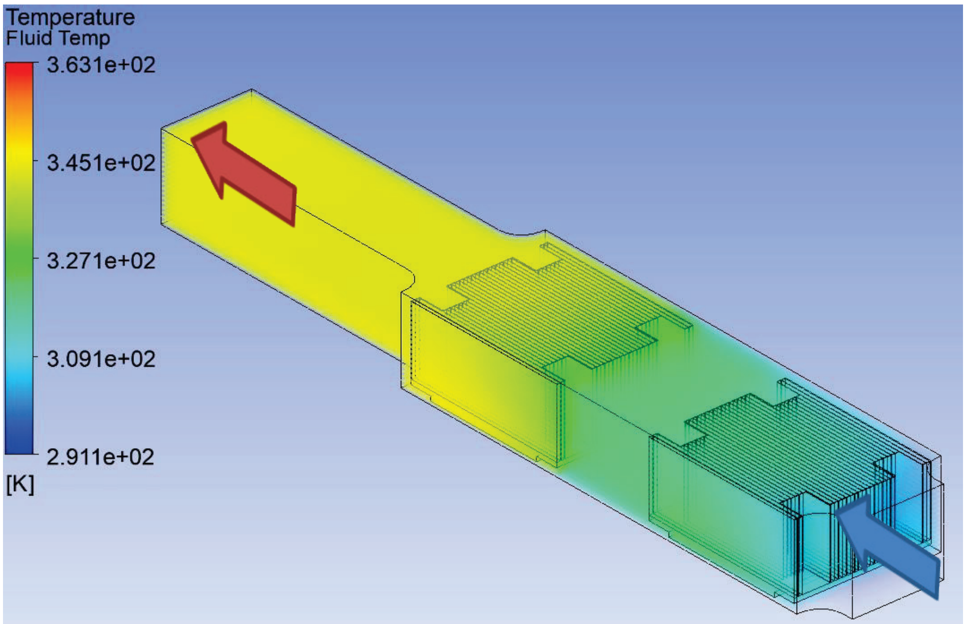


Figure 4: Temperature simulation of the concept "tunnel" with a final temperature of 71°C at the red arrow.

The concept for the "tunnel" was further developed where the theoretical model was made more complex with labyrinthine entrances over the CPUs. With the modification, the simulation results showed an outlet temperature of just over 80 °C. The physical tests for the modified concept measured an outlet temperature of just over 50 °C, which is a worse outcome contrary to what the simulation showed. The difference between theoretical and practical outcomes is most likely explained by shortcomings in production and in-leakage of cooler oil from the environment.[21]

3.2 CONNECTION PRINCIPLES FOR THE TEST BEDS

In order to make the best use of the excess heat from the data center, it was decided that domestic hot water or the associated circulation circuit would be interesting points for connection and thus could constitute a fictitious district heating network. Based on this, four possible connection possibilities were identified:

A) VVC to VV,

B) VV to VVC,

C) VVC,

D) VV

The purpose of the various alternatives was to clarify the possible combinations that exist for connection and supply of the excess heat, in order to be able to evaluate which alternative is most advantageous.

Connection alternative A

The purpose of the connection VVC to VV (Figure 5) is to cool the IT load and at the same time heat the hot water in the VVC circuit to then discharge directly into the VV system. This heat exchange was simplified in the diagram as a plate heat exchanger marked W-004 and the same simplification was used for the following concept diagrams, however with a different marking. That connection is equivalent to heating water from the return line to the supply line in a district heating network.

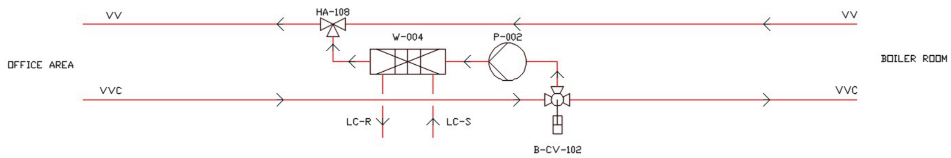


Figure 5: Diagram for connection possibility VVC to VV.

Connection alternative B

The purpose of the connection VV to VVC (Figure 6) is the reverse where water is taken from the VVC circuit to be heated to a higher temperature on the VV system. That connection is equivalent to heating water from the supply line to the return line in a district heating network. Using the HVAC system as a connection point would result in too high temperatures in the servers. This connection does not normally occur in a district heating context but is thus a possible connection combination.

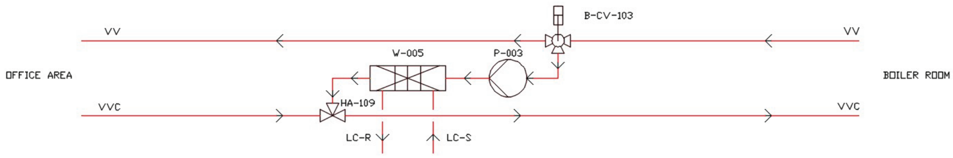
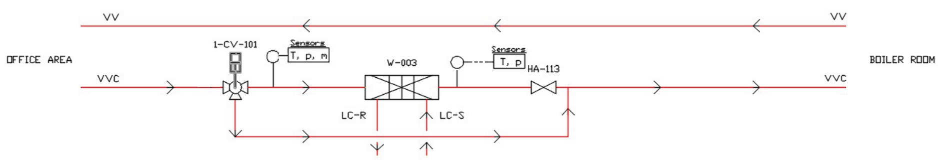


Figure 6: Diagram for connection possibility VV to VVC.

Connection alternative C

The purpose of the VVC connection only (Figure 7) is to focus only on heating the VVC circuit and thereby be able to reduce the heat demand in the domestic hot water exchanger in the substation. It was considered the most advantageous option for the property; however, it would be equivalent to heating the return line in a district heating network.



Figur 7: Diagram for connection alternative VVC.

Connection alternative D

Analogous to connection alternative C where the HVAC circuit heated, connection alternative D refers to heating of the HVAC circuit. Using the water in the DHW circuit as a connection point would mean a high temperature of the coolant to the server's equivalent to connection alternative B. That connection corresponds to heating from the supply in a district heating network.

3.3 TECHNOECONOMICS

In order to evaluate the advantages and disadvantages of liquid-cooled systems, from an economic perspective, some cases were calculated for the increase in income that district heating sales to a district heating company would entail. In addition, the space efficiency was evaluated, which means how many servers can be placed on one surface in comparison with traditional air cooling.[20]

3.3.1 Cost comparison

As a basis for the economic calculations, three different systems were compared in Table 1;

- Asperitas, their product can be compared to a "bathtub" with space for 42 servers, they are an established player in the immersion cooling market,
- EPS, a simpler solution with space for two servers developed on RISE based on an EPS isolation framework,
- Air cooling, refers to a traditional rack for air cooling with space for 42 servers.

All prices are calculated without servers, IT solution and other refrigeration equipment such as CRAH units, compressors, cooling towers, piping and ventilation. For liquid-cooled data centers where there is a possibility of using the excess heat, the cooling machine and cooling tower can be eliminated and make the technology more competitive compared to air-cooled data centers.

Tabell 1: Cost comparison between Asperitas, EPS solution and traditional air cooling

	Asperitas	EPS	Luftkylning
Cost	511 817: -	2 352: -	17 973: -
Number of servers	48	2	42
Cost/server	10 663: -	1 176: -	428: -

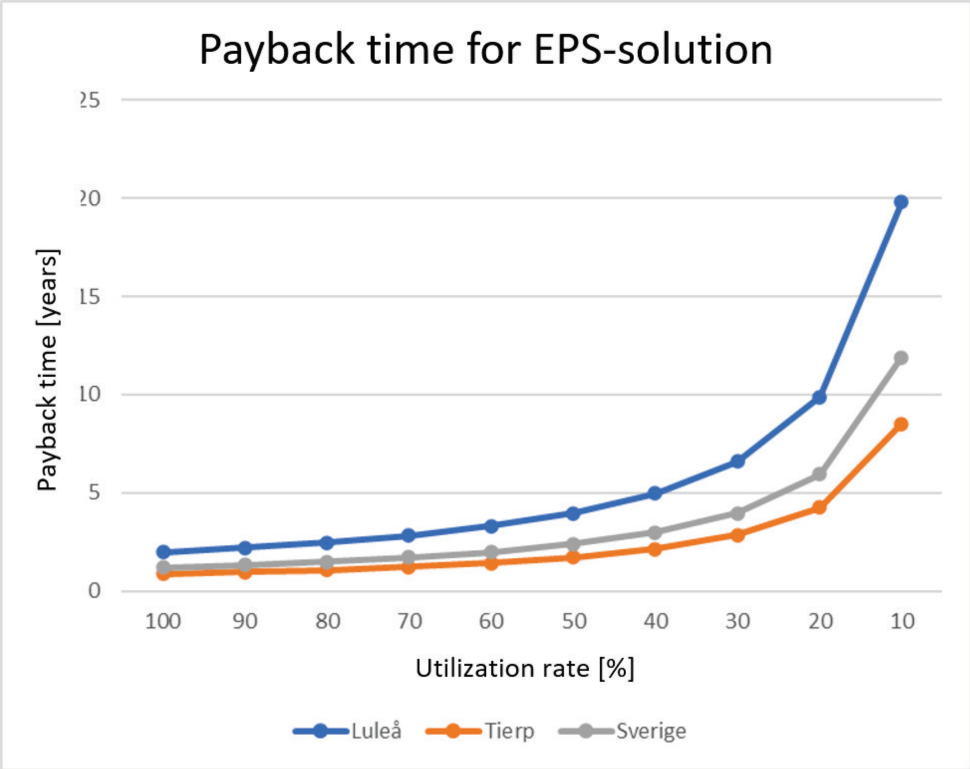
What is clear is that an Asperitas server site costs almost 10 times more than the EPS solution and that an air-cooled server site is less than half the cost compared to the EPS solution. In order to be able to compensate for that additional cost, some form of income needs to be generated, which could be done if the surplus heat can be sold as district heating.[20]

When using modern servers that have a maximum power of 800 W, a rack could be equipped with up to 25 servers instead of 42, before the maximum rack power of 20 kW is reached. This means that it takes about double the number of racks to be able to cool all servers in a good way. With immersion cooling where the cooling is better, it is possible to pack the servers close to each other and in that case that technology will be more space efficient.

3.3.2 District heating sales

A major advantage of liquid cooling is the ability to extract higher levels of usable heat compared to using air cooling, sufficiently high temperatures are reached 60 - 80 °C can then be sold as district heating. Figure 8 shows a summary of three scenarios for district heating sales; Luleå, Tierp and the Swedish section[25]. Marked in the graph is the repayment period for the Sweden case.

Since the income from the IT services is assumed to be independent of the cooling solution, the calculations reflect the repayment for the additional investment linked to liquid cooling compared to air cooling. A high sales price can compensate for a poor utilization rate of the installed IT capacity, while in places with a low sales price or poor utilization rate, problems can arise.[20] The possible utilization rate of the servers is strongly linked to the type of data center; mining (cryptocurrency), enterprise (data center under its own auspices) or co-location (rental of server space), where mining usually has 100% and for enterprise and co-location in the range 20 60% but they also strive for full utilization.



Figur 8: Pay back time for EPS-solution in Luleå, Tierp and Sweden in average for different utilization rates.

3.3.3 Space efficiency

To evaluate space efficiency between air cooling and liquid cooling, a comparison has been made using drawings from a real server room at the ICE data center. The server room is designed as a traditional data center with four CRAH units for cooling the rack, the existing servers in the server room have a maximum power of 400 W per server, which is used in the calculations below.

The base case is the air-cooled servers that are currently located there and the comparison case is based on the same room but with the EPS solution for liquid cooling instead.

The placement of cabinets and the EPS solution in the room is limited by the need for space for service, necessary machinery in the form of UPS and switch equipment and the door that must be accessible. However, the door in question opens outwards, hence accessibility to the door is the only thing that matters.

The server room is about 5 meters wide and 6.5 meters long, which gives an area of about 33 m^2. Based on drawings from RISE, simplified pictures have been drawn that illustrate the placement of server cabinets and liquid-filled rigs, respectively.

In Figure 9, it is clear that the cooling units occupy a large area that limits how many rack cabinets it is possible to place in the room. In a liquid-cooled system, these cooling units are not needed, which can be an advantage.

The total number of rack cabinets is 10 and each cabinet can hold 44 servers, which gives a total number of 440 servers in the room20 corresponds to a total power of

176 kW and 97% is converted to heat, which has a potential to recover 170 kW of heat.

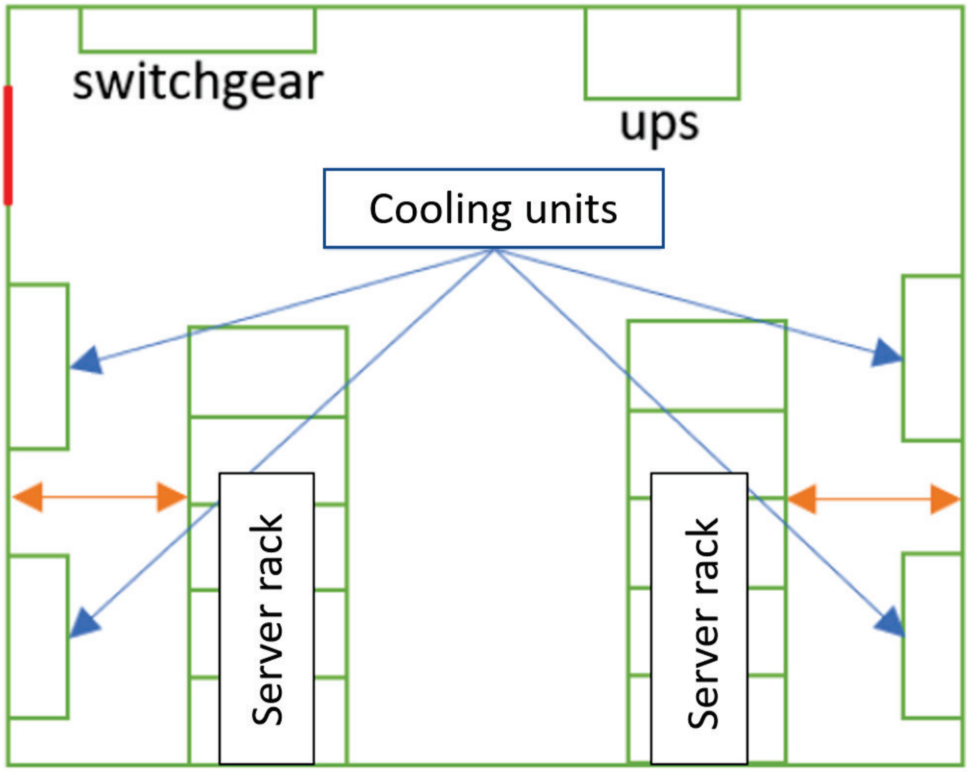


Figure 9: Design of current server room at ICE data center based on air-cooled server systems.

There are several benefits to liquid cooling when it comes to placement. For the liquid-cooled EPS solution, it is calculated that it is possible to place two rigs on top of each other with a shelf solution for weight relief.

In a liquid-cooled system, it is not necessary to separate all the rows as air does not have to have a free path between. No air-cooling units are needed either.

The biggest limitation of the liquid-cooled solution is that they need to be accessible for service, in addition, there is no obstacle to filling the room's total floor space.

In total, Figure 10 places 168 EPS solutions, with two servers in each solution. Three different placement configuration options were evaluated. As a result, a total of 336 servers can be accommodated.

When the surface is taken into account, the resulting occupied floor space for each server is 0.098 m^2 and 0.075 m^2 for the EPS solution and traditional air cooling, which shows that traditional air-cooled rack cabinets are more space efficient compared to the EPS solution. This is even though the liquid cooling has a more flexible placement option, largely due to the fact that the large amount of insulation in the EPS solution is made up of.[20]

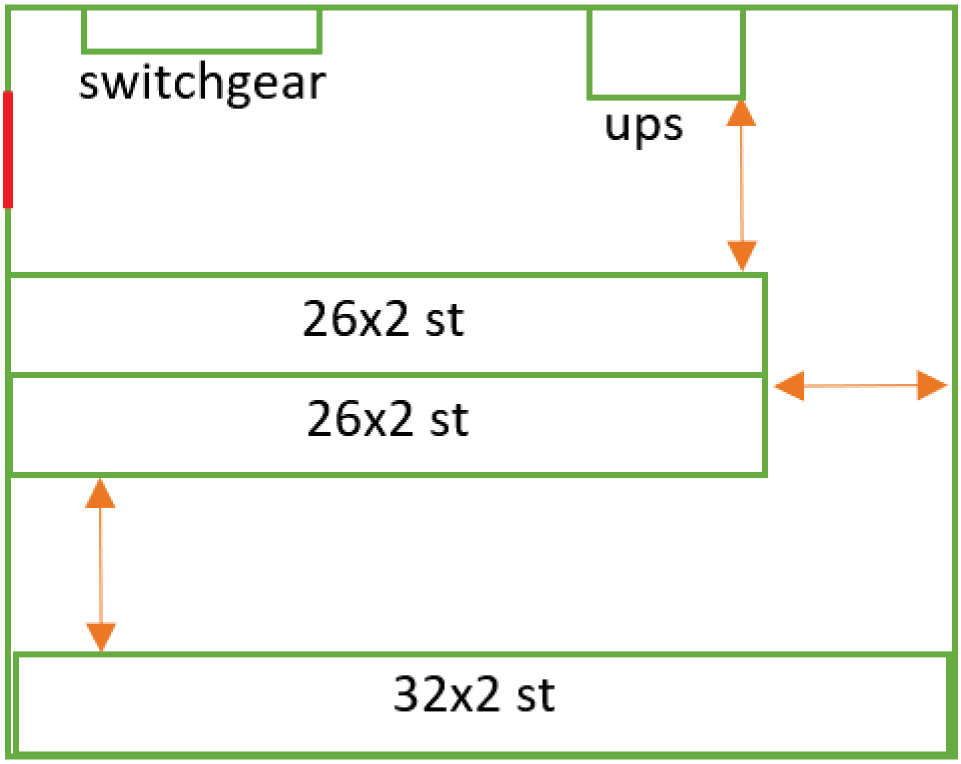


Figure 10: Possible design of server room at ICE data center for installation of EPS solution for liquid cooling.

3.3.4 Comparison in energy density between data centers and district heating production

Within a district heating system, there are always a number of production facilities that have different purposes to cover base and tip loads, within the reference group for the project, information has been collected about their existing production facilities. Table 2 below clarifies the energy density for different production facilities and data centers, which shows that in some cases a data center facility can obtain the same energy density as a wood-fired district heating system, however, it depends on the type of data center.

Table 2: Comparison of power intensity between traditional district heating production facilities and data centers.

Fuel	Building area	Plot area	Power	Spec. power intensity	
				Building area	Plot area
	m²	m²	MW	kW/m²	kW/m²
Biogas, oil	-	22 000	450	-	20,5
VP, Biomass, oil	-	25 000	355	-	14,2
Wood chips	-	46 000	55	-	1,2
Bio-oil	1 100	12 000	74	67,3	6,2
Biomass	5 400	128 000	75	13,9	0,6
DC Boden (Mining container 1)	9	45	1,8	200	40
DC Boden (Mining container 2)	14	70	0,6	45	9,0
DC Stackbo (Enterprise)	24 000	226 730	500	20,8	2,2
DC Ersbo (Enterprise)	24 000	174 149	290	12,1	1,7
DC Boden (Mining)	41 565	38 991	19	0,46	0,5
DC Luleå (Enterprise)	-	325 539	212	-	0,7
DC Vallentuna (Enterprise)	-	4 500	0,6	-	0,1

3.4 LIQUID COOLING TEST BED

The liquid cooling test bed is the name of the center on which calculations were performed in the project.[23] It is to the central that various liquid cooling technologies must be able to be connected and evaluated for the production of useful heat for the property. Which provides a good basis for both driving the data center industry and the use of low-value surplus heat going forward.

3.4.1 Connection principles

The VVC circuit inlet to the test bed takes place in line 1. To avoid overheating, a heat exchanger for emergency cooling (position 2) was installed, it is fed from the property's cooling system.

[23] Lundmark, 2021

Two control valves (positions 3 and 4) distribute the HVAC flow to the two heat exchangers (positions 5 and 6) to which the servers are connected. One heat exchanger (5) for oil-based cooling and the other for water-based cooling (6).

Outlets take place in line 7, back to the VVC circuit and the rest of the building.

Temperature, pressure and heat energy are measured at several points in the test bed, marked with T, p and Q.

An auxiliary pump is located between position 1 and 2 to overcome the local pressure drop and also be able to take over the supply of the HVAC circuit.

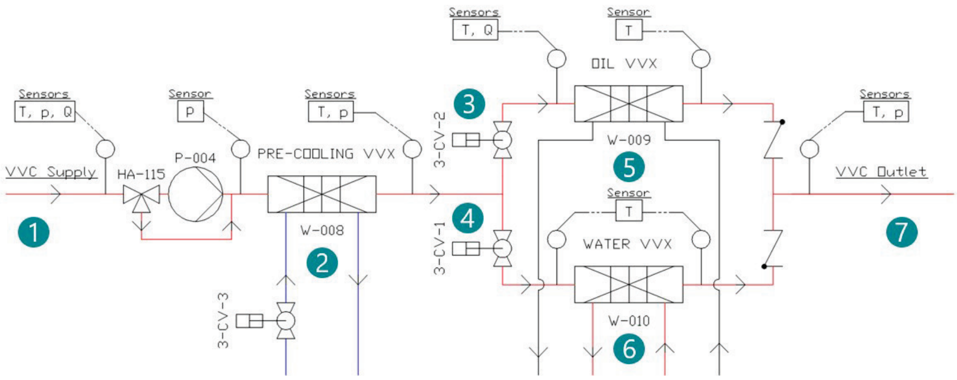


Figure 11: Diagram of the established liquid cooling test bed

By regulating the flow to the IT load's cooling equipment, the temperature to heat exchangers 5 and 6 can be controlled, which corresponds to a flow control in a heat production plant to achieve the correct flow temperature in a district heating network.

3.4.2 Dimensioning

In order to be able to dimension the test bed, an Excel model was created to be able to calculate design parameters such as heat demand, liquid flows and temperature differences.

XSteam Tables is a tool for Excel that enables dynamic calculations in water based on, among other things, temperature and pressure, which is a useful tool for creating a dynamic and reliable model.

The model was built up by creating blocks that had a logical connection to each other. Each block had a set of properties for input (input) to the block and output (output) where the next block input was often identical to the previous block output and thus created a link between the blocks.

3.4.3 Installation

To facilitate installation and to gain an understanding of how large an area the test bed would need, the plant was designed with components, piping and dimensioning.

A local plumbing company was hired to complete the installation from the plumbing in the ceiling and down to floor level as well as the installation of the test bed and all its components.

The assembly of sensors and electronics was performed by RISE's own staff, where a Raspberry Pi was used as the main data collector for temperature and flow sensors.

The pressure sensors were read using AD converters from the company Moxa, which was also used to send setpoint signals between 0–10V to the control valves.

3.4.4 User interface

The interface was developed for touch screen use where the components are clickable. When clicked, a dialog box opens that allows the user to either get more information from a specific area (for example, a heat exchanger and all connection points to it) or check the setpoint for a control valve.

The interface has a total of seven clickable objects, three control valves, three heat exchangers and the pump. The refresh rate for the interface is approx. 1 time per second and is determined on the state server, which is the server that retrieves measurement data from the database.

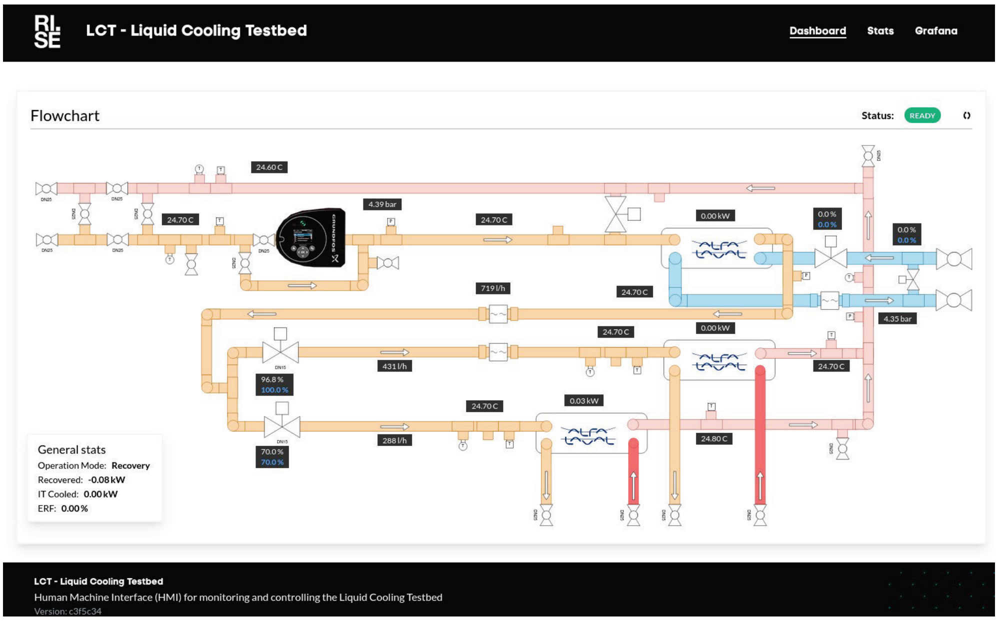


Figure 12: User interface (HMI) for liquid cooling testbed.

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4 Discussion

One of the most difficult challenges when it comes to achieving the desired temperature for, for example, a district heating application, not just the heating effect from cooling components, is the number of switching steps. At each change step, the initial temperature decreases, which is one of the main reasons why you want to run liquid-cooled instead of air-cooled.

The heat from a processor is first transferred from the core to the protective cover, which also acts as a heat spreader. A heat sink or a cooling block (if it is liquid cooling) is mounted on the protective cover, which means that two switching steps are already required for the heat to be transferred from the processor before it can be transferred to an efficient means of transport, such as water.

When using air-cooled racks, however, there is another step where the heated air must be switched an extra step via a CRAH before liquid form is reached. This is primarily since air has a significantly poorer heat transfer capacity and specific volumetric heat capacity than water. Thus, significantly higher temperature differences and larger volumes are required to transfer the corresponding amount of heat compared to water as a heat carrier.

Immersion cooling with oil directly to a plate heat exchanger on the receiver side, for example district heating, results in the smallest number of heat transfer steps. However, the heat exchange from the hottest components is not as concentrated, which in that case can be compared with air.

An interesting concept would be to combine on-chip with immersion cooling, in order to achieve the highest possible temperature of the excess heat. Immersion cooling is used as a first temperature rise which is then led into an on-chip which makes the last temperature rise. Since the processor is the hottest unit, it is important that it and the liquid out of the on-chip are isolated from the rest of the oil in the immersion cooling system.

A complement to this, to also take advantage of the lower tempered heat from the oil, would be to heat the last step with a heat pump, which is a well-known heat upgrade technique, with the challenge of avoiding too many heat pump steps.[24]

The project has shown that there are theoretical possibilities to be able to achieve 80 °C on the recovered heat without a heat pump from immersion cooling technology. However, more product development needs to be done both theoretically and practically to be able to extract it, larger margins in calculations and simulations as well as smaller tolerances in production.

If the desired temperatures are reached, a data center could be a heat source for a low-temperature district heating network with a supply temperature of 80 °C and 40 °C on the return line.

The data center systems that currently recycle heat to district heating generally need half the data center effect as a heat pump effect, which often has large effects.

[24] Davies, Maidment & Tozer, 2016

In cramped electricity sectors where there is a lack of power, liquid splicing is a good alternative and in cases where the temperature level becomes too low, the heat can be upgraded with a heat pump. What proportion of the data center effect the heat pump would correspond to in that case is unknown, which is something that could be studied at the established test bed.

The most challenging part of this work has been the starting point to try to dimension a system with very few known significant variables such as IT loads, nominal flows and temperature differences for connecting systems, etc. This means that many assumptions must be made by the person who dimensions and performs the work but also additional difficulties in contact and consultation with companies that usually sell and dimension their products based on fixed operating points. This results in a spiral effect where all assumptions and variables become directly dependent on each other with few known points that can be used to verify the arrangement before it is ordered, installed and tested. This can also lead to the person dimensioning taking extra height and oversizing certain components which entails extra costs and can result in poorer technical results. For example, both the pump and the heat exchangers in this system had to be selected based on the worst possible operating scenario. It is not certain that the worst-case scenario will occur, nor that it will be most optimal for the final operation. At the same time, this is part of the development work when it comes to research and "Test and Demo" (T&D) facilities, where based on the results in the future you can learn how to dimensions and what you can improve.

Another important question that arises in a project like this is how the system, to which the test bed is connected (which in this case is the VVC) responds and how its control and function are affected by different operating cases and rapid changes in the server effect. In this case, unfortunately, the system could never be tested with an increased return temperature out, as no sufficient IT load was available before the end of the project.

Most likely, the property's district heating plant will be able to handle a higher HVAC return temperature without problems, a temperature that is higher than the setpoint for the hot water. This is because the substation is equipped with an extra shunt valve at too high a temperature on the outgoing hot water line. However, this should be validated during testing with IT load and production of heat where any problems on the receiver side are corrected if possible, via the building's control system.

5 Conclusions

During the project, it has been possible to process the main issues with the following conclusions:

[F.1] The highest possible temperatures on the excess heat are extracted directly above the servers' CPUs, experiments in a lab environment have succeeded in extracting 72 °C as the highest temperature. That temperature is sufficient for implementation in a low-temperature 4-generation district heating system, as well as summer temperature in several district heating networks. To upgrade it to high-temperature district heating, heat pumps can be used, through liquid cooling instead of air cooling, half of the heat pump effect can be eliminated, which makes it more economically justified to use to recover the excess heat.

[F.2] and [F.3] By using only liquid cooling instead of air cooling for traditional servers, the power intensity does not increase. With new and more powerful servers and HPC clusters, racks can be made more energy-efficient by using liquid cooling instead of air cooling, when more heat can be transported per unit volume. In comparison with production facilities in a district heating system, there are certain cases where a data center achieves the same energy density, especially those production facilities that use biomass.

[F.4] Based on traditional air-cooled server racks, it is an additional cost with a factor of 3 for the EPS solution and 25 for Aspertias per server space. Provided that the total server power in a full rack does not exceed 20 kW, which is the upper limit for the cooling capacity of air-cooled racks.

[F.5] In the project, 4 different connection principles have been analyzed with the aim of recovering heat from the data center, where a building's HVAC circuit has been allowed to constitute a fictitious district heating system. The most suitable principle is to heat water from the return line to the supply line (VVC to VV), the same principle as a normal heat production plant. Another possible connection is VVC to VVC, which would correspond to heating the return line in a district heating network, which in modern networks is avoided when it is at the expense of the power in the boiler for the flue gas condensation.

[F.6] When ranking the different cooling techniques for data centers, immersion cooling is most advantageous for a data center owner as it requires less technical installation compared to on-chip cooling.

[F.7] The biggest obstacle to the implementation of liquid cooling is mainly the large additional cost it entails. By developing simpler and cheaper solutions, there is great potential to be able to influence the industry.

The second obstacle is knowledge when the data center owner's business model focuses on selling IT services and not producing district heating. Through research, this knowledge can be created and disseminated to promote the use of liquid cooling.

There is a clear trend in the industry that several data center players see an added value in using their surplus heat in some form to create a stronger environmental profile, which strengthens their brand.

The third obstacle is cooperation and ownership responsibility to clarify who is responsible for what and how the agreements between the parties are designed, which is the key when heat from a data center is to be recycled to a district heating network.

[F.8] A liquid cooling test bed has been established at the ICE data center facility that enables testing and evaluation of liquid cooling techniques, as well as heat recovery of them in the liquid phase as domestic hot water. Which provides great opportunities for holistic research and product development where the entire system can be tested and evaluated.

6 Future work

There are several issues to work on further within this project.

6.1 CONNECTION OF IT LOADS

At present, the liquid cooling test bed has only been tested with servers which are air cooled then switched to water before it reaches the test bed and hence only low temperatures can be achieved. There are already two sets of EPS rigs at RISE that are approaching to be ready to be connected to the test bed, but both have their delays and the installation of an Asperitas similar oil-based set-up has taken significantly longer than expected.

6.2 DEVELOPMENT OF CONTROL SYSTEM

One work that remains is to develop a control system that is linked to all input data (flows, temperatures, pressure drops, etc.) that is available. The system would then control control valves, pumps and shunt valves to achieve the desired results regarding possible heat recovery and the ability to set a desired setpoint at the outgoing temperature of the VVC leaving the test bed.

That system could then be further developed and refined to suit other and more applications, with the main purpose of being simple and stable for both upscaling and downscaling.

6.3 IMPACT ON MATERIALS AND IT COMPONENTS

Running IT components at a higher operating temperature than recommended is already known to have many disadvantages. A disadvantage is that when the temperature above the processor is raised, the energy consumption also increases due to larger leakage currents, but also that higher temperatures can adversely affect the service life of the components.

This project is prepared to take these IT risks with the focus on demonstrating heat recovery that is otherwise often neglected, with the hope that, for example, 10-15% increased losses in the form of leakage currents would still motivate heat recovery.

The service life of the components must also be included in this, but since this type of test takes a very long time to carry out and validate, step one is first to investigate whether it is even possible before investigating all risks.

It would also have been interesting to carry out a life cycle analysis to investigate any increased material consumption that may be required due to the components aging faster and to put heat recovery in perspective towards the manufacture of new components.

A system analysis should be carried out that studies the relationship between data center and district heating system, is there any optimal data center size in relation to the district heating system's installed power. Furthermore, also find the balance or equilibrium between the heat pump power and the data center power when liquid cooling is used.

Based on the information above, a SWOT analysis should finally be carried out for a district heating system with a liquid-cooled data center as a heat source, which creates a basis for the energy companies to be able to work further with and work on the issue.

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VIRTUAL HEATING PLANTS

Data centers can replace existing heating plants in a district heating system if the right cooling technology is used and IT hardware can achieve the same power intensity. A testbed has been created to support the technological development of liquid-cooled data centers. The goal is to be able to create excess heat that does not need heat pumps to be used in a district heating network.

The project aims to demonstrate the opportunities and obstacles that exist to switch from air cooling to liquid cooling of data centers, with it being able to allow data centers to constitute as virtual heating plant in the district heating system.

To enhance the use of liquid cooling in data centers for heat recovery the biggest obstacles are; the additional cost for more expensive technology, knowledge of the properties of the technology, lack of cooperation models, and division of ownership responsibility between the data center owner and the recipient of the surplus heat.

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